

FINAL REPORT

Sensitivity of global thermohaline ocean circulation to disintegration of West Antarctic ice shelves and ice sheet

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1 Project objectives, results and conclusions

We accomplished our aim, to test the hypothesis that disintegration of the West Antarctic Ice Sheet (WAIS), or just its ice shelves, may significantly perturb regional and global ocean circulation. For this test we used a coupled ocean/sea-ice model (POP-CICE) developed at Los Alamos National Laboratory.

Removal of shelf- and land-ice exposes up to a few million square kilometers of new polar sea surface area to sea-ice formation, causing the volume and the extent of Antarctic sea-ice cover to increase significantly as compared to the control run. Large polynyas open in the Ross embayment when only ice shelves are removed, while they open in the Filchner-Ronne embayment when the whole West Antarctic Ice Sheet is removed. Cold and saline water masses form in polynyas, leading to downwelling. Where polynyas are not present, development of a more persistent, continuous, and thicker sea-ice cover enables stable stratification with cold but relatively fresh mixed layer and warm intermediate and deeper waters. The global oceanic circulation is also affected, strengthening the Southern Ocean bottom circulation cell. This strengthening is associated with increased southward meridional heat transport, dominated by flow at intermediate and deep water depths. At the same time, sea-surface temperatures drop in southern mid to high latitudes by as much as 0.75°C . Far-field effects are concentrated in the North Atlantic, where deep circulation weakens, and sea-surface temperatures drop by 0.2°C after only 40 model years.

We conclude that changes in the extent of WAIS may have significant impact on sub-Antarctic and global ocean circulation and should be considered as a possible link between the dynamics of WAIS and global climate variability.

2 Summary of research results

2.1 Background and approach

Global ocean and climate models typically assume a fixed land mask for the Antarctic continent, neglecting the potential for dynamic behavior of ice sheets on timescales relevant to decadal- and century-scale climate simulations. During the last decade, however, several small West Antarctic ice

Bathymetric grid modification

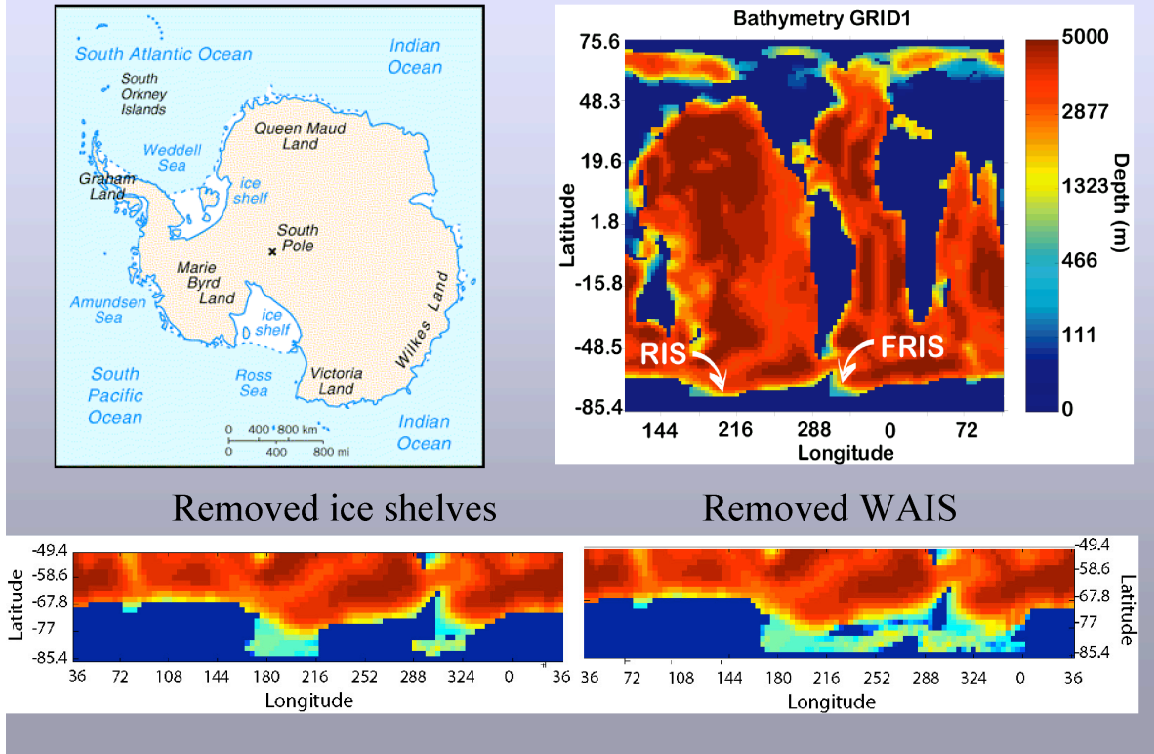


Figure 1: Modifications made to the model bathymetry for the two experiments. Upper right plot shows the global bathymetry, indicating the Ross Ice Shelf (RIS) and Filchner-Ronne Ice Shelf (FRIS). Lower left shows the bathymetry with those two shelves removed, and lower right is the bathymetry with the West Antarctic Ice Sheet removed.

shelves experienced sudden collapse, in some cases triggering accelerated flow of inland ice. These observations strengthen the existing concern about the near-future stability of WAIS. The Ross Ice Streams, which are like rivers of ice flowing within the ice sheet, are slowing down, and as a result the Ross Ice Shelf may disintegrate because the ice that supplies it will no longer be available. The ice shelves (Ross and Filchner-Ronne) buttress the ice sheet itself. It has been observed that when smaller ice shelves collapse, the ice upstream begins to drain much more quickly. That could tip the mass balance toward the negative side; it is possible that if the Ross and Filchner-Ronne ice shelves disappear, that the entire West Antarctic ice sheet could collapse.

The purpose of this project is to see how that scenario might affect the global ocean circulation. The experimental procedure consists of a control case, with modern configuration of ice in West Antarctica, and several numerical experiments in which the model landmask and bathymetry are modified to simulate collapse of West Antarctic ice shelves and ice sheet. Fig. 1 shows a map of the Antarctic continent, with the Ronne-Filchner and Ross ice shelves south of the Weddell and Ross Seas, respectively, along with plots of the bathymetry used for the control simulation and the two test cases.

In order to do these runs, we had to modify the model configuration and implement an atmospheric mixed layer parameterization that adjusts the atmospheric input data for different surface conditions. Where glacial ice is removed, revealing the open ocean surface, atmospheric properties such as temperature and humidity must be altered to account for the change. All runs were executed over 40 model years. Subsequent experiments were designed to test the changes due to the great influx of fresh water from the melting ice.

2.2 Major Findings

The results of our numerical experiments demonstrate that changes in the extent of shelf- and land-ice in West Antarctica may have significant influence on sub- Antarctic and global ocean circulation. This is in spite of the fact that the areas exposed from underneath the thick ice cover in our experiments represent just 0.3% (no-ice-shelves case) and 0.6% (no-ice-sheet case) of the global ocean area. Yet, these small perturbations are capable of changing the value of the simulated overturning stream function by as much as 32% in the Southern Ocean. More polynyas occur in the Ross area when the shelves are removed; more in the Filchner-Ronne when WAIS is removed (Fig. 2). Water beneath the perennial ice cover is warm, while cold, saline water is associated with the polynyas. The surface ocean in polar regions cools by up to 0.75°C . Furthermore, removal of WAIS opens ocean channels that significantly affect ocean circulation. These changes in the temperature and salinity of the ocean affect the circulation that is driven by density differences, and that in turn affects the global heat transport. Fig. 3 shows the change in north-south heat transport from the no-shelves run and the run without the West Antarctic Ice Sheet, compared with the control. Southward heat transport increases by up to 0.1 PW toward the ice sheet; this is a significant change since the total heat transport to *both* poles is about 4 PW. In the no-WAIS case, where the entire ice sheet collapses, the southward heat transport increases dramatically, which would accelerate further melting in the Antarctic.

Our interpretation is that this high sensitivity of ocean circulation and sea-surface conditions to changes in West Antarctic ice cover stems from the fact that removal of shelf- and land-ice in this region intensifies sea-ice production and associated brine extraction.

Over the last three decades, glaciological research in Antarctica has been motivated by a concern about the possibility of near-future sea-level rise caused by unsteady behavior of WAIS. However, the potential impact of WAIS instability on ocean circulation has been overlooked. We have documented that ocean circulation is highly sensitive to the configuration of WAIS. This finding opens a new direction in the research on the role of Antarctic as an important component of the global climate system.

We also tested the effect of imposing the atmospheric mixed layer model. It has a significant effect, even at lower latitudes, and we plan to follow up on this with additional analyses, perhaps with help from a summer student.

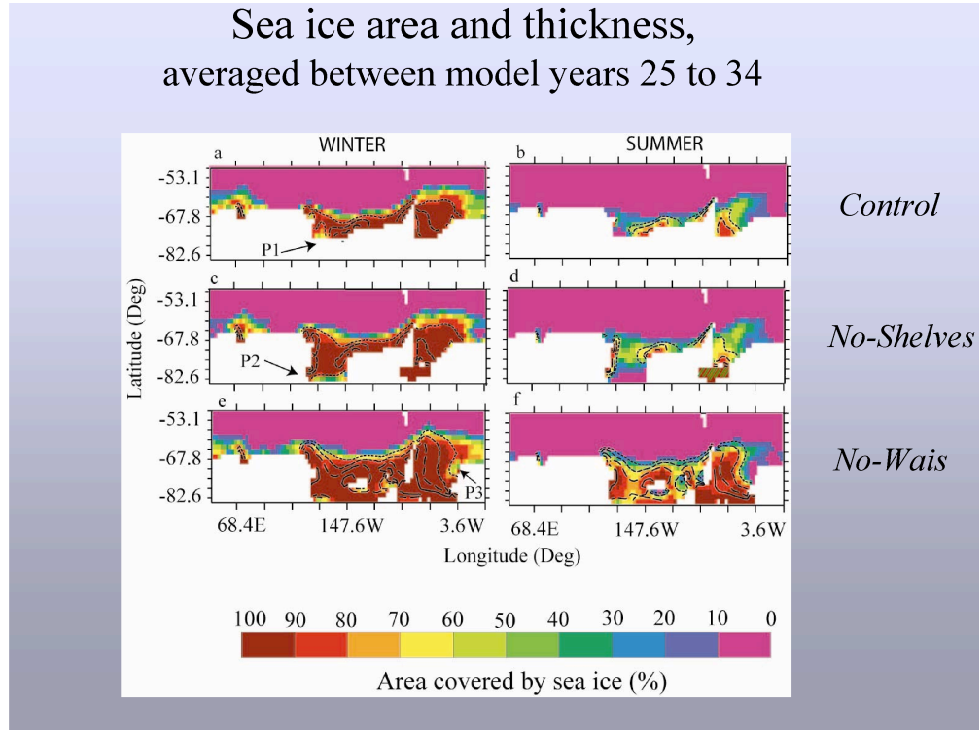


Figure 2: Changes in the area coverage of sea ice in the experiments, compared with the control run. Polynyas are indicated P1, P2, and P3.

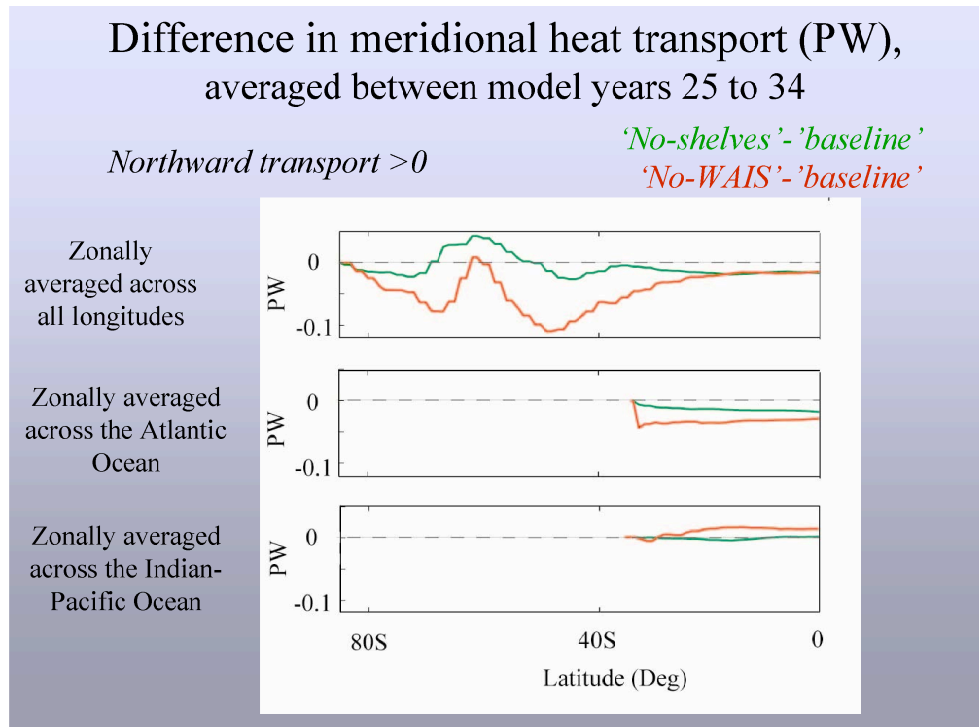


Figure 3: Changes in meridional heat transport for the experiments, compared with the control run.

2.3 Progress During the Past Year

Preparation of new input files for testing the influence of freshwater release on sub-Antarctic circulation

We have prepared new input files necessary to perform the numerical tests planned under the second renewal proposal. The tests are aimed at evaluating the impact of increased freshwater release from Antarctica on ocean circulation. This stage of our work was hindered by Dr. Marion Bougamont's graduation with her Ph.D. in May 2003 and subsequent move to the U.K. to work as a research fellow at the Bristol Glaciological Centre in September 2003. To replace Marion, Dr. Poul Christoffersen was hired in March 2004 to work part-time on this project as a postdoctoral fellow.

Attempts to run the new numerical tests

Our attempts to run new numerical experiments, testing the effect of fresh water fluxes from melting ice shelves and WAIS on the ocean circulation, have been frustrated by a string of computer problems related to a protracted process of replacing the high-performance computer available to Dr. Hunke, and by other security related shutdowns at Los Alamos. These problems made it impossible to complete the work outlined in the second renewal proposal. Moreover, Dr. Christoffersen took a faculty position at the University of Wales at Aberystwyth in September 2004 and is available for helping with the final stages of this project only on a limited-time basis.

Progress with publications

For Marion Bougamont this IGPP project represented the second part of her dissertation project, which she completed successfully in May 2003.

The chief editor of Journal of Climate asked us to revise and resubmit the first manuscript resulting from this project (Bougamont et al., in review). We resubmitted it in summer of 2004 and it is now in re-review.

3 Products

3.1 Publications

Bougamont, M., E. C. Hunke and S. Tulaczyk. Sensitivity of ocean circulation to the disintegration of West Antarctic ice shelves and ice sheet. Submitted to *J. Clim.*, 2003.

Bougamont, M. "Transient Behavior of the West Antarctic Ice Streams: Implications for Global Sea-Level Changes and Ocean Circulation." Ph.D. dissertation, Univ. of California, Santa Cruz, June 2003.

3.2 Presentations

Tulaczyk, S., E. C. Hunke, I. Joughin, M. H. Bougamont and X. W. Vogel. Possible abrupt changes in ocean circulation and climate due to the changing behavior of Ross ice streams, West Antarctica. EOS Trans. AGU Fall Meet. Suppl., 82 (47), Abstract IP22C-10, 2001.

Bougamont, M., E. C. Hunke and S. Tulaczyk. Short-term sensitivity of sub-Antarctic and global thermohaline ocean circulation to disintegration of West Antarctic ice shelves. EOS Trans. AGU Fall Meet. Suppl., 83 (47), Abstract C51A-0919, 2002.

Bougamont, M., E. C. Hunke and S. Tulaczyk. Short-term sensitivity of the global thermohaline circulation to West Antarctic ice sheet and shelves disintegration. Los Alamos National Laboratory, March 2003.

Tulaczyk, S., E. C. Hunke and M. Bougamont. Sensitivity of ocean circulation to disintegration of West Antarctic ice shelves and ice sheet. 10th WAIS Workshop, Sterling, VA, September 2003.

Bougamont, M., E. C. Hunke and S. Tulaczyk. Disintegration of West Antarctic ice shelves and ice sheet: Implications for the oceanic circulation. European Geosciences Union, Nice, France, April 2004.

3.3 New capabilities

In the course of this project, the UCSC PI gained new expertise in physical oceanography and ocean modeling. This enhances his ability to perform future research at the interface of glaciology and oceanography. It is a very timely development because interactions between the polar oceans and ice sheets are becoming a new frontier in polar sciences.

Additionally, an atmospheric mixed layer module was developed and tested within the coupled ice-ocean model framework, significantly affecting the global model simulation. This module will be used for other ice-ocean coupled modeling studies.

3.4 Collaborations & contacts

This award supported collaborative work between the UCSC PI and Dr. E.C. Hunke, and also supported a graduate student during the final phase of her Ph.D. work. In addition, during his visits to LANL the UCSC PI made contacts with Dr. W. Lipscomb, which led to a new IGPP grant to further improve the sea ice model.

Drs. Bougamont and Christoffersen remain interested in the project, and we all intend to continue the collaboration to the extent possible. In creating the input fields for the next simulation phase, Dr. Christoffersen worked with Dr. Rupert Gladstone of the University of Bristol, who has expertise modeling ice berg drift tracks and their associated melt water fluxes in the Southern Ocean. With

Dr. Gladstone’s assistance, our simulations that include melt water fluxes will be more realistic.

A list of visits and seminars by the team members is given in the table below.

Collaborative exchange between UCSC and LANL scientists				
Date		Personnel	Facility	Notes
October	2001	Tulaczyk Bougamont	LANL	Tulaczyk: IGPP seminar
February	2002	Hunke	UCSC	IGPP seminar
December	2002	Hunke	UCSC	Bougamont: AGU presentation
March	2003	Tulaczyk Bougamont	LANL	Bougamont: COSIM talk
May	2003	Hunke	UCSC	Bougamont: Ph.D. defense
June	2004	Tulaczyk	LANL	IGPP seminar

4 Resources used

4.1 Funds received as a result of IGPP-sponsored research

We have not yet pursued external funding.

4.2 Los Alamos facilities used for this project

All resources are located in the Theoretical Division except for the computers, which have been partly owned by the DOE Climate Change Prediction Program and administered by the Advanced Computing Laboratory and Los Alamos’s institutional computing project. Dr. Hecht is based in the CCS division.

Hardware resources used: the Nirvana (SGI Origin 2000) and Guyot (SGI Origin 3000) platforms.

Software resources used: the POP-CICE model, the SCRIP interpolation package for regridding input data, and some post-processing tools developed at LANL.

LANL experts consulted: Drs. E.C. Hunke, M. Maltrud, and M. Hecht.